

# CONSEQUENCE CALCULATIONS FOR PPCS BOUNDING ACCIDENTS

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## **Abstract**

*A 'worst case' assessment of the radiologically significant environmental source term, based on bounding accident analysis of a single blanket cooling loop LOCA, has been performed for Fusion Plant Models A and B of the Power Plant Conceptual Study (PPCS). This paper describes the calculations of ensuing material mobilisation, transport in the containment, release to the environment and consequential dose to the public. Also reported is a comparison with more detailed dose calculations by FZK, for the same scenario, using real weather data. The results show that the calculated doses are comparable with, or slightly above, typical annual doses from natural causes.*

## **1 INTRODUCTION**

This paper describes bounding accident analyses of Fusion Plant Models A and B of the Power Plant Conceptual Study (PPCS) [1], performed in order to obtain a 'worst case'

assessment of the radiologically significant environmental source terms, and to derive bounds, in terms of dose, for consequences to the public. Also reported are comparisons with the results of probabilistic dose calculations performed at Forschungszentrum Karlsruhe (FZK) [2].

The bounding accident scenario assumes complete loss of cooling by all circuits in the plant, and the complete inventory of one first-wall/blanket cooling loop is assumed to be released into the vacuum vessel, as a result of an in-vessel pipe rupture. During this blowdown phase the coolant, which may be carrying activated corrosion products (ACP), escapes from burst pipes, entrains dust and tritium in the vacuum vessel, and enters some dedicated volume through a suppression-pool system (if incorporated in the design). Following blowdown, the decay-heat in various plant components drives a temperature rise, leading to mobilisation of further materials through volatilisation.

Modelling of the transport of mobilised material in the containment is performed using FUSCON [3], which models the plant from the time immediately following blowdown. The inventories made available by this process are derived from the assumptions specified in reference [4]. FUSCON makes use of volatilisation data produced by the APMOB code [5] and employs aerosol modelling in the calculation of release from the containment system.

The remainder of this paper describes the mobilisation and release calculations, and consequent upper bound dose estimates.

## **2 MOBILISATION AND RELEASE**

Material which can potentially be released comprises coolant, ACP, dust, tritium, and volatilisation products which emanate from some of the hotter components following decay-heat-driven temperature rise. The assumed coolant and source-term relevant inventories needed to evaluate this were obtained from [4]. The specification of the nuclide inventory for the dust is derived from data for Eurofer at the outboard midplane first wall, and the tungsten divertor armour [6,7]. Additionally, the composition of the ACP inventory for Plant Model A was derived from a combination of data from studies using PACTOLE [8], and TRACT [9].

### **2.1 Mobilisation from solid components**

Volatilisation products emanate from the first wall and blanket as a result of the temperature transient caused by an in-vessel LOCA in a single blanket cooling loop. This is conservatively calculated on the assumption of total loss of all cooling [10]. The loss is assumed instantaneous, and there is no heat removal by any active cooling system, nor is any other active safety system operational. Heat rejection is therefore only by passive conduction through the layers of the plant and radiation across the gaps. This is a much more severe condition than the single-loop LOCA designated as the bounding accident, and which actually determines the components which provide the source of the volatilisation.

The mobilisation calculation is performed using the code APMOB [5] which makes use of the temperature predictions and the inventory of nuclides calculated by FISPACT [6,7,11].

## 2.2 Release calculations

Release calculations are dependent on a number of assumptions about the progression of the accident sequence and, for plant model A, a small number of alternative options were considered. Of these alternatives, the worst case was a scenario in which it was postulated that a failure of all quartz windows occurs in a single RF beam port in the vacuum vessel wall . Hence the VV and the, now connected, RF room (assumed to be of 100 m<sup>3</sup> volume) are assumed to be pressurised to the containment design maximum of 0.16 MPa immediately following blowdown. The active blowdown products (dust, ACP and tritium) are deemed to occupy the outer containment from this time with the dust and ACP assumed to have undergone scrubbing. The dust and ACP masses are therefore modified by the scrubbing factor of 0.198, but the whole of the tritium is assumed to pass through the scrubbing system unmoderated.

Two separate calculations were performed for this scenario. The first was to determine the environmental source term deriving from the blowdown products and the second to do the same for the volatilisation products. The calculation of the volatilisation component is conservative as a result of neglect of the interaction with the blowdown products. A number of other conservatisms were also involved in adapting the problem to the FUSCON architecture. The calculated contribution from volatilisation is negligibly small, although the calculation provides an upper bound.

For model B, all mobilised material is assumed to occupy the dedicated expansion volume at time zero. In addition to being governed by the processes of aerosol physics, this material is

deemed to leak into the environment at a prescribed rate (1% per day at design overpressure) appropriate for a steel-lined expansion volume.

For both Plant Models A and B, the volatilisation products arise after blowdown has completed and are continuously mobilised at a varying rate throughout the course of the 7 day period following the hypothetical accident. However, to simplify the calculation, it is assumed that the whole of the inventory becoming available during this period exists from time zero, and is perfectly mixed.

### **3 ULTRA-CONSERVATIVE DOSE ESTIMATES**

By employing a set of combined dispersion and dose factors, which were obtained under stringent assumptions involving worst-case fixed-weather (thus no wind-meander, i.e., the tendency for wind to change direction) with a 1 hour release duration, and which were previously used in the SEAFP study [13], estimates have been obtained of the 7-day dose to the most exposed individual (MEI) at the site boundary (1 km radius) arising from the calculated source term. These results, representing ultra-conservative upper bounds which the 7-day MEI dose is, in reality, unlikely to attain for the accident considered, correspond to ground level release, and are summarised in table 1. Note that all tritium has been conservatively assumed to be in HTO form.

Calculations of dispersion and dose have also been carried out at FZK [2] for the accident analyses described in this paper. These calculations are probabilistic and are based on records of actual weather statistics gathered for the FZK site. The source term employed in this case was an earlier version of the one published here, but it has been verified that the differences

are insignificant. According to reference [2], values corresponding to the 95%-fractile of the dose probability distribution are often employed in regulatory guidelines for licensing nuclear installations, which usually involve potential evacuation criteria of 50 or 100mSv for the MEI. We will therefore focus on this particular category of result for the comparison.

The above dose estimates were obtained for assumed worst-case fixed-weather, and so those results provide a type of upper bound to the potential doses. We have made a comparison between those values and the 95%-fractile values (for 1 hour release-duration) given by the probabilistic FZK calculations. There is less than a factor two difference between the upper bound estimates and the 95%-fractile results. So deterministic calculations with worst-case fixed-weather can be a useful guide to an important dose statistic.

#### **4 LESS CONSERVATIVE DOSE ESTIMATES**

We now scale the results for realistic release-duration, which necessitates taking into account the phenomenon of wind-meander. This effect leads to reduction of the exposure of the MEI as release-duration increases. A general method for doing this, based on an empirical formula, was outlined in reference [12] and is now employed here to assess its suitability.

The FZK results were obtained for 3 release durations: 1 hour, 24 hours, 7 days. Figure 1 shows these 95% fractile results for the tritium and solid aerosol components of Plant Model A. Also shown for each component is the corresponding result obtained by taking the 1 hour results and applying the wind-meander correction for other durations. It can be seen that the wind-meander scaling matches well the scaling with release-duration of the probabilistic results. This gives confidence that these methods can be used to obtain good estimates of

doses corresponding to the 95% fractile for a range of release durations, and reinforces the general value of the deterministic calculations. Thus, in situations where more exact probabilistic calculations are not available, such estimates are able to provide a useful guide to the potential consequences.

During the 7 day period we are concerned with, the characteristic timescale for release to the environment, for each and every source term component, fell into the range 1 – 7 days. By taking the 24-hour-release dose values, we can ensure conservatism. The 95%-fractile values for the 7-day MEI dose distributions, as given by reference [2] for 24 hour release, are shown in table 2. These values are a little greater than, or similar to, typical annual doses from natural causes.

## **5 CONCLUSIONS**

Bounds on consequent dose to the public were derived in bounding accident analyses for two PPCS plant models and validated by comparison with calculations performed at FZK which showed that the conservatively calculated doses are a little greater than, or similar to, typical annual doses from natural causes.

The analysis has shown that the combined dispersion and dose factors previously used in the SEAFP study, combined with an adjustment for wind-meander, can produce good estimates of dose statistics for arbitrary release durations and realistic weather scenarios.

## 6 ACKNOWLEDGEMENTS

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## TABLES

**Table 1.** Summary of ultra-conservative dose estimates.

PLANT MODEL	SOURCE	UNIT DOSE (Sv)	REL. FRAC	FINAL DOSE (Sv)
A	PMA FW	9.44E+00	7.57E-07	7.15E-06
	PMA Divertor	6.87E+01	7.57E-07	5.20E-05
	PMA Tritium	7.30E-01	1.36E-02	9.94E-03
	PMA ACP	7.25E-02	3.53E-03	2.56E-04
	PMA Dust	9.36E-01	3.53E-03	3.30E-03
	TOTAL			1.36E-02
B	PMB FW	3.45E+01	1.82E-03	6.28E-02
	PMB Divertor	1.67E+01	1.82E-03	3.04E-02
	PMB Tritium	7.30E-01	8.06E-03	5.88E-03
	PMB Dust	8.83E-01	1.82E-03	1.61E-03
	TOTAL			1.01E-01

**Table 2.** Conservatively calculated doses (mSv) to the most exposed individual from the hypothesised bounding accidents, for Plant Models A and B.

Plant	Dose
PMA	1.2
PMB	18.1

## FIGURE CAPTIONS

**Figure 1.** Values of the 95%-fractile of the dose probability distribution (solid lines) for Plant Model A at 3 release durations for the tritium (upper line) and solid aerosol (lower line) components. Also plotted for both cases is the wind-meander scaling (dotted lines).

